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Use of temporary gas flow to improve the efficiency of metallurgical units operation

V I Matyukhin[1, 2], A V Matyukhina[1], S Ya Zhuravlyov[1] and N V Yamshanova[1]

[1] Institute of New Materials and Technologies, Ural Federal University named after the First President of Russia B N Yeltsin, 19, Mira str., Yekaterinburg, 620000, Russia

E-mail: [2] matyhin53@mail.ru

Abstract. This paper presents the results of industrial tests on dust deposition due to the use of an unsteady gas flow. JSC SUMZ (Revda) applied the technology with the use of acoustic radiators to organize in-furnace dust deposition at Vanyukov furnace. The design of the radiator included a nozzle pipe, air nozzle, resonator and focusing surface. Based on the surface area of the furnace molten pool and recommended specific acoustic power values for in-furnace dust condensing, the total acoustic field sound power was calculated. The optimal number and location of acoustic radiators was determined. The analysis of the data of industrial tests of the use of the acoustic field energy in the working space of the PZhV, as well as the results of tests on the converter No. 2 of JSC 'SUMZ', the cyclone of the firing multi-hearth furnace of JSC 'SVYATOGOR', the dust chamber of the Waelz furnace and cleaning of the heat exchange surfaces of the boiler on waste gases (JSC 'Chelyabinsk Zinc Plant').

1. Introduction

Thermal performance of the majority of process units using disperse materials of various fineness or processing of supernatant liquid is characterized by the formation of a significant (up to 200–250 g/m^3) amount of dust particles of various grain fineness, their sticking to the inner surface of gas ducts and furnace elements with limited kinetics of the main physical and chemical processes. In order to reduce losses of initial and finite materials and to improve the environmental situation in the area of the enterprise location on the way of dusty gases movement a number of dust-arresting equipment (dust chamber, cyclone unit, electrostatic precipitator) are installed in series. Despite their relatively high capture efficiency factor, the content of dust particles in the exit gases remains high. Such a state of technology and design of furnaces is characterized by a significant tension of the gas exhaust duct, process equipment installed on it, losses of initial materials for the main production, increase in environmental impact on the environment [1–4].

2. Research of ways to reduce dust emission from layered technological units

One of the most rational ways to reduce dust discharge from the layered process units is to improve the conditions of dust-laden flow movement at all technological stages in order to optimize the gas-dynamic situation in the working compartment. As the largest source of dust, the working compartment of the unit can be used for in-furnace dust deposition. At the same time, captured dust particles increase the amount of materials involved in technological processes, increasing their performance and reducing the amount of thermal losses with exit gases.

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One of the effective and low-cost ways to improve the performance of process layered units or their individual parts is the use of temporary gas flows based on the use of acoustic field energy and their specified pulsations formed directly at the place of use.

The basis for the development of such processes are the theoretical positions in the formation of impulse energy effects of rational power on the processed materials, taking into account the transformation of energy fields, evaluation of intensity of physical and chemical effects, the inversion of their use in changing environmental conditions of facilities existence.

Correctly chosen impulse energy impact and effective manifestation of emerging effects of intensification of basic processes is the basis for the creation of energy-efficient and environmentally friendly technology.

The external acoustic field or the field of gas pulsations created in a homogeneous space is a source of vibrational impact on moving dust particles or lumpy batch mixture elements. This is due to local periodic changes in gas pressure in the moving flow from positive to negative. Excess gas pressure between the particles caused by external oscillations is compensated by the outflow of excess or insufficient amount of gas in the direction of oscillations propagation. In this case, an additional flow of the gas medium occurs, which contributes to the intensification of heat – mass exchange processes by 10–15 %.

In the presence of resonance of the external acoustic field frequencies and the natural frequency of the dust particles, due to oscillations of solid particles, the amplitude of which is determined by the initial parameters of the acoustic field, there is the occurrence of low-frequency small-scale contours of the particles movement without deviation from the original movement pattern (Figure 1). The following total pressure is applied to each solid particle of dust-laden flow with a density ρ that is in the field of external acoustic or pulsatory oscillations with amplitude A and circular frequency ω in a gas medium at a speed of sound c

$$P = P_o + A \cdot \rho \cdot c \cdot \omega \cdot cos(\omega(t - \frac{x}{c})) \text{, atm.}$$

In addition to the total pressure of the moving gas P_o, an additional periodic force with an oscillation amplitude acts in the external acoustic field with sound level J

$$P_a = A \cdot \rho \cdot c \cdot \omega = \frac{\rho \cdot c \cdot \omega}{\omega}\sqrt{\frac{2 \cdot J}{\rho \cdot c} \cdot 10^7} = \sqrt{2 \cdot J \cdot \rho \cdot c} \text{ , atm.,}$$

the value of which can be changed through the design and process parameters of the process with a change in the value of input actions. The latter cause the destruction of the boundary layer near oscillating particles and the occurrence of additional convection flows in a moving gas medium.

Large-scale contours of circulating groups of particles, which lead to the occurrence of piston effect, can appear in discharged media. The piston effect phenomenon is manifested in the formation of local vacuum near periodically moving particles, which causes the formation of additional convection flows. Absolute values of local pressure and discharge near the individual particles depend on their size, frequency and amplitude of oscillations. In this case, the frequency of the external field pulsations shall coincide with the natural frequency of oscillations of the main mass of the particles. Experimental measurements of local pressures in the layer, by the example of vibrated fluidized bed, showed the possibility of achieving its value up to 20000 Pa.

This effect is the most noticeable in the conditions of those technological processes, where there are small values of gas velocities, and the gas flow is characterized by an increased content of dust. The bigger is the transverse size of particles, the bigger is the level of created rarefaction. Therefore, when acoustic or pulsatory fields of the given parameters are formed, small particles will move to the coarse ones around which a local zone of increased rarefaction is formed, forming around them an area with an increased concentration of fine dust elements. Under prolonged exposure to periodic oscillations, it provides the ability to hold dusty fractions around coarse particles, reducing dust discharge by up to 20–25 %. In this case it is necessary to take into account the time factor of the acoustic field action.

The process of acoustic or pulsation coagulation of dust particles will be most effective when it is organized directly in the working compartment of the process unit. However, this process requires an individual approach.

In the implementation of intra-unit dust deposition, it is necessary to implement the following principles:

1. The most complete and continuous effect of external oscillations on the dusty environment. For this purpose, in accordance with the design features of the unit, it is necessary to determine the location of sources of temporary action installation with the possibility of maximum impact on the dust-laden flow or dispersed medium.
2. Necessity of implementation of the time factor of acoustic influence on the dusty flow.

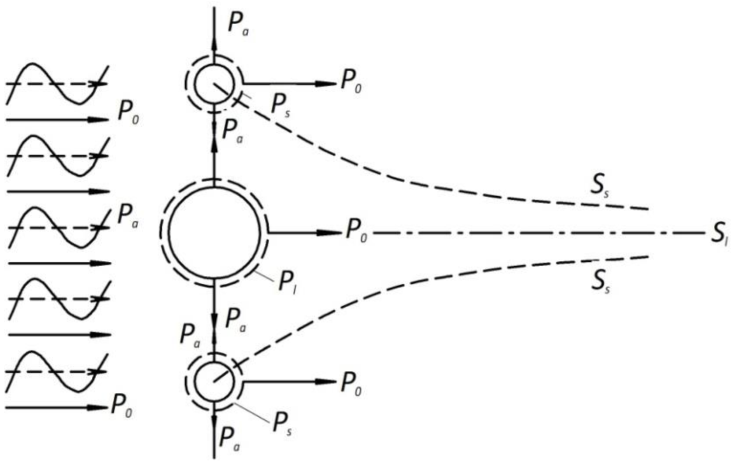

Figure 1. Diagram of acoustic influence on solid elements of the layer:
P_o – static pressure of gas flow; P_a – acoustic pressure; P_s – rarefaction near small elements;
P_l – rarefaction near large elements; S_s – small elements movement pattern;
S_l – large elements movement pattern.

3. Formation of the acoustic field of the set parameters established in accordance with the design features of the unit and physical and chemical characteristics of dust particles. For this purpose, the optimal design and technological parameters of acoustic jet-edge radiators or gas flow pulsators, providing the maximum development of the required technical effect (reduction of dust discharge, intensification of heat – mass exchange processes, destruction of dust outgrowths and crusts, etc.) are set by means of a calculation or experiments.
4. Industrial tests of the use of acoustic field energy or pulsatory gas flows with the evaluation of the efficiency of dust deposition and development of heat – mass exchange processes.

The formation of the acoustic field in the layer is proposed to be performed with the help of an acoustic radiator (Figure 2, 3) using waveguides of various designs or mechanical pulsators, taking into account the properties of the transported medium.

Acoustic radiator is a kind of gas-dynamic Hartmann whistle and consists of a nozzle, resonator and focusing plane made of metal. It is powered by a compressor air with pressure of at least 3.0 atm. in an amount up to 50 m^3/h. Installation of this unit is carried out outside the working compartment, and it facilitates its installation, maintenance and operation, as well as reduces the requirements for the materials from which it is made. The use of an acoustic field directly in the working compartment of the process unit makes it safe for maintenance personnel.

In conditions of limited, for technological reasons, impulse energy impact on the objects of intensification with the required low frequency of oscillations (large volumes of working compartment, low speeds of gas flows, limited process temperature), real prerequisites for the application of pulsating air blast flow are created. The transmission of mechanical energy of oscillations in this case can be realized mainly through the dynamic forces of the moving, as a whole, gas flow with periodically varying value, and its part merging with the main flow within the working compartment [5–10].

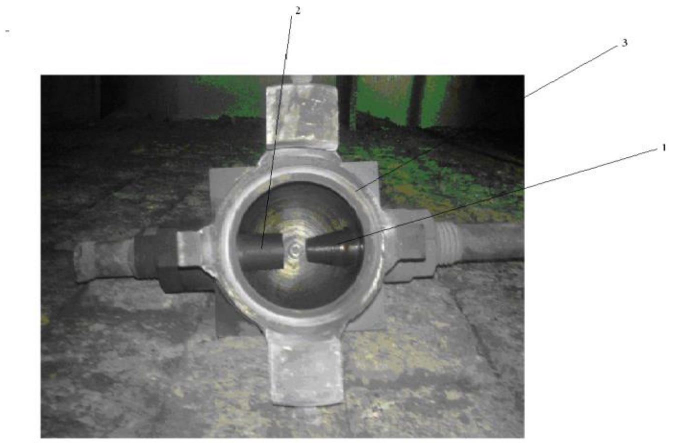

Figure 2. Acoustic radiator: 1 – nozzle; 2 – resonator; 3 – focusing plane.

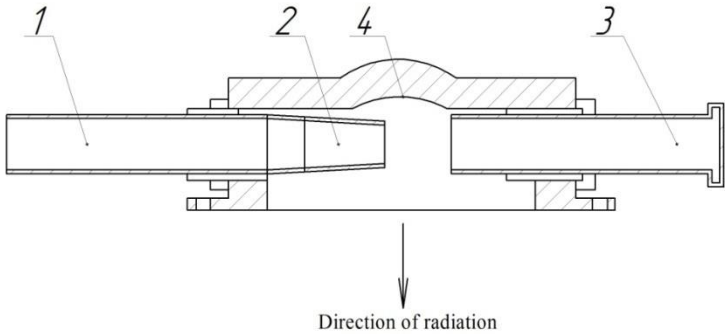

Figure 3. Acoustic radiator design:
1 – nozzle pipe; 2 – air nozzle; 3 – resonator; 4 – focusing plane.

Depending on the value of mass pulsating flow, the general nature of gases oscillatory movement development, energy efficiency of their use, the amount of energy consumption for their generation are changed. Oscillations of the entire mass of the gas flow lead to large inertial loads, which limit the scalability of this method. The second type of pulsating flow using only a part of the moving gases may be more attractive, but with a smaller manifestation of the change in efficiency. The resulting oscillations of the gas medium inside the system accelerate the process flow. However, a lower value of the resulting impact limits the range of variation in the frequency of oscillations not exceeding 50 Hz.

Industrial tests of the use of acoustic field energy for the intensification of heat - mass exchange processes on a number of process units (sinter machine, a dense bed of curing oven, cast iron and mineral-cotton cupola furnaces, mining unit of non-ferrous metallurgy) have shown wide possibilities of this method application.

Thus, industrial tests of this process in the conditions of sinter machine AK-50 of Serov Metallurgical Plant for a long time confirmed the safety of its use. In addition, it was shown that it is possible to increase the performance of the unit by up to 15–20 %, increase the depth of the main physical and chemical reactions in the bed, reduce harmful emissions from the sinter machine (CO, NO_x, dust), reduce specific fuel consumption per process by 10–15 %.

Depending on the design of the fibrous materials curing oven, from two to six radiators were manufactured and assembled in vacuum and drying chambers. Their tests showed the possibility to increase the performance of the unit by 30–35 % with the improvement of the quality of organic binding substance use.

The results of using the acoustic field energy in the working compartment of cast iron and mineral-cotton cupola furnaces, mining units of non-ferrous metallurgy (Kirovgrad) showed a possibility to increase performance of smelting units by 10–15 % with a corresponding reduction of coke consumption and harmful emissions by 20–25 %. At the same time, the destruction of the resulting crusts during the movement of gases and materials is also noted, and it increases the performance of the smelting unit and reduces its maintenance costs.

Formation of sound oscillations field of the given parameters in a moving dust-laden flow of finely dispersed batch mixture of rotating furnaces of alumina production of the Bogoslovsky Aluminum Plant with a diameter of 3 m and a length of 60 m, both in the direction of movement of gases and in the opposite direction allowed to establish a steady tendency of dust discharge reduction outside the working compartment by up to 40 %. At the same time more full completion of all chemical transformations in solid components, with the destruction of the resulting crusts on the inner surface of the drum was observed.

Measurements of environmental conditions in the test area allowed to establish a slight change in working conditions of the maintenance personnel by the sound pressure level [11–16].

The analysis of data from industrial tests of the use of acoustic field energy in the working compartment of smelting reduction furnace (SRF) (SUMZ, Revda) showed that at approximately the same consumption characteristics of the original components, the use of acoustic energy leads to a decrease in dust discharge by 10.94 %. At the same time, the in-furnace dust deposition leads to the increase of matte output by about 406 kg/h and slag output by 1.299 kg/h. With an average copper content of 51.7 % in the matte, this provides an opportunity to increase the amount of copper received by up to 210 kg/h.

Test results on converter No. 2 of JSC SUMZ using acoustic field energy of two radiators with 3.0 atm. pressure installed in a dust chamber and two radiators at cyclone inlet in Table 3 showed that during the first period of melt reforming the total degree of gas dust exclusion increased up to 56-72 %. During the second period, the degree of dust deposition using acoustic radiators increased by 22 % on average.

If the dusting system is connected directly with the process unit by circulation of gases or dust components, the acoustic effect on its individual devices can have a significant impact on the operating conditions of the entire process. Thus, when acoustic radiators are installed at the cyclone inlet nozzle of the multihearth roaster of JSC SVYATOGOR, its total efficiency has changed in comparison with the normal mode from 57.14 to 70.49 %, i.e. by 13.35 abs.% or by 23.36 r.% due to dust coagulation directly at gas flow movement in the cyclone working compartment.

To assess changes of dust deposition conditions in the dust chamber of the Waelz kiln and cleaning of heat-exchange surfaces of the boiler on the exit gases (Chelyabinsk Zinc Plant PJSC), acoustic radiators were installed on the dust chamber in the end wall towards the movement of gases, and on the heat-exchange surfaces of the boiler – in the upper area of the lifting channel against the movement of gases. It was shown that all other conditions being equal, the use of the acoustic field energy allows increasing the output of reverse dust by 8.74 % due to intensification of the process of intra-unit coagulation in the sedimentation chamber by up to 25–30 %, and the output of velyokis` by 2.99 % due to reduction of hydraulic resistance of the dust chamber and the boiler while increasing the actual gas velocity.

Thus, under the influence of an external acoustic field of the given parameters or a pulsating gas flow on the dusty flow there are conditions for the convergence of coarse and small particles and dedusting of exit gases directly in the working compartment of process units or their individual areas. The practice of using this process at a number of units has shown that each place of installation of the radiator can reduce the dust flow by about 20–25 % from the initial. It is also possible to destroy the formed dust deposits (fully or partially).

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3. Conclusion

Insignificant capital and operational costs of using the energy of the acoustic field and pulsating gas flow for the organization of intra-unit dust deposition open up prospects for improving the environmental situation in the area of operation of layered units of various designs and improving their energy.

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